Modelling of passive mode-locking in Quantum Dot Lasers: a comparison between a Finite – Difference Travelling Wave model and a Delayed Differential Equation approach

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Modelling of passive mode-locking in Quantum-Dot Lasers: a comparison between a Finite-Difference Travelling-Wave model and a Delayed Differential Equation approach

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In this work, we provide a quantitative comparison between a finite-difference travelling-wave (FDTW) model [1] and delayed differential equation (DDE) approaches for the simulation of passive mode-locking (ML) in quantum-dot (QD) lasers. FDTW models allow to accurately describe two-section ML lasers with both Fabry-Perot (FP) and Ring cavity geometries but they usually require a large computational time [1]. On the contrary, the DDE model frequently used in the literature, e.g. [2-4] for QD but also for QW ML lasers, represents a simple and computationally efficient approach but several assumptions are introduced in its formulation: a unidirectional ring cavity is assumed (Fig. 1a-b), spectral filtering due to the finite gain bandwidth, output losses and intrinsic waveguide losses are introduced as lumped elements in a single reference section of the device (z=0) (red arrow in Fig. 1a-b); finally only two sections acting as gain and saturable absorber (SA) are assumed. Despite these assumptions, DDE models have often been applied to the analysis of ML in QD

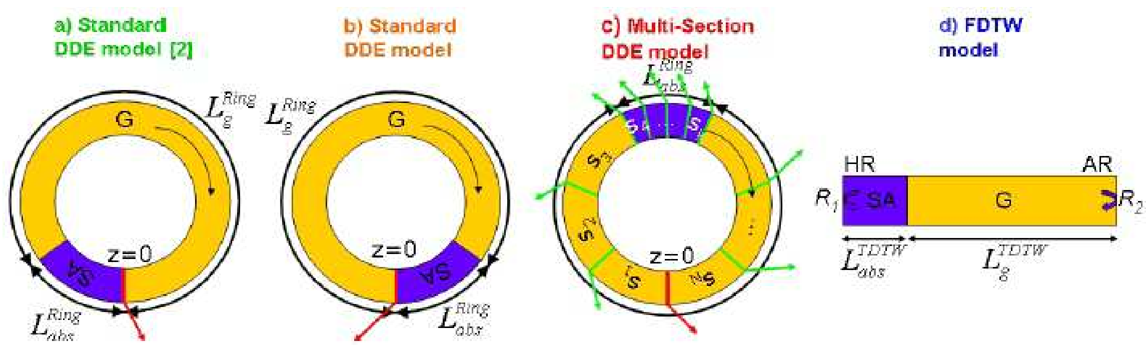

Fig.1 (a-b) Scheme of ring lasers described by a standard DDE model; (c) ring laser simulated by the multi-section DDE model; (d) schematics of FP laser modelled via the FDTW model.

ML lasers with FP cavity geometry [3,4]. In Fig. 2, a quantitative comparison between simulation results obtained using the FDTW model on a QD Fabry Perot ML laser (Fig. 1d) and results obtained using a standard DDE model on the equivalent ML ring lasers (Fig. 1a-b) reveals large differences in the obtained dynamic regimes. In order to improve the agreement between the two methods, we propose a modified DDE approach that allows to take into account an arbitrary number N of electrically isolated sections ($N \geq 3$), allowing to properly describe the alternative equivalent ring structure reported in Fig.1c. The modifications introduced allow to significantly improve the agreement with the results obtained with the

FDTW model (Fig. 2). The proposed multi-section DDE model can therefore be successfully used in extensive analyses of QD ML lasers with FP cavity geometry.

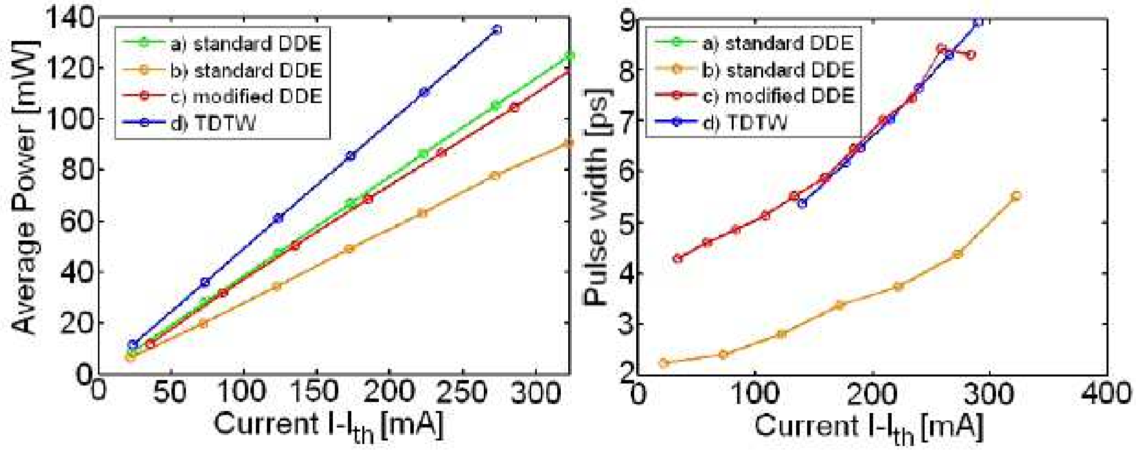

Fig.2 Average power and pulse width vs. current obtained at a fixed 7V SA voltage for the structures reported in Fig.1, using respectively a standard DDE model (a-b), the proposed multi-section DDE model (c) and the FDTW model (d). Structure (a) (green) shows a continuous-wave operating regime.

[1] M. Rossetti et al., *IEEE J. Quant. Elec*. (2010) in press.
[2] E.A. Viktorov et al., *Appl. Phys. Lett.* **88**, 201102 (2006).
[3] M.A. Cataluna et al., *Appl. Phys. Lett.* **90**,101102 (2007).
[4] E.A. Viktorov et al., *Appl. Phys. Lett.* **91**,231136 (2007).

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